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㉚ Material for cutting tools, use of same and cutting tools.

㉛ Cutting tools and materials for cutting ferrous work-pieces at high cutting speed comprise:

- a) a substrate based on a matrix composed of at least one selected from the group consisting of oxides, nitrides, carbides and oxinitrides of aluminum, silicon and IVa group transition metal elements in the International Periodic Table, the substrate comprising 5 to 50% by weight of SiC whiskers with respect to said substrate, the whiskers being uniformly dispersed therein; and
- b) one or more coating layers composed at least one of oxides, nitrides, carbides, borides and oxinitrides of at least one of aluminum, IVa and Va group elements in said Periodic Table, said coating layer being formed on the surface of said substrate to a thickness ranging from about 0.3 to about 20 µm.

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MATERIAL FOR CUTTING TOOLS, USE OF SAME AND CUTTING TOOLS

This invention relates to materials for cutting tools, use of the same in cutting and cutting tools.

- As the cutting tools for the high speed cutting of ferrous or other metallic work-pieces, there have generally been known those which are composed of the following materials: (1)  $\text{Al}_2\text{O}_3$  type or  $\text{Si}_3\text{N}_4$  type ceramic sintered body; (2) TiC type cermet; (3) cemented carbides coated with ceramic materials such as  $\text{Al}_2\text{O}_3$ , etc.; and so on. Of these various materials, the  $\text{Al}_2\text{O}_3$  or  $\text{Si}_3\text{N}_4$  type ceramic sintered body itself has no sufficient mechanical strength, hence it could not be applied for machining steel, although it was practically used for cast iron machining. As for the TiC cermet, while it possesses a higher mechanical strength than the above-mentioned ceramic sintered body, it considerably reduces its wear-resistant property when the cutting speed becomes increased so that the material imposes on itself a limit to the cutting speed. The ceramic-coated cemented carbide, on the other hand, has its own disadvantage such that, owing to the poor chemical affinity between the ceramic coating and the substrate, differences in the thermal expansion coefficient, and so on, the ceramic coating suffers from peeling off when the cutting speed is increased or an impact force is imparted to the work-piece with the consequent lowering in its wear-resistant property or occurrence of defect therein, which also imposes on the material a limit to the range of its use.
- It is therefore a primary object of the present invention to provide a material for cutting tools which are widely applicable to various ferrous work-pieces and capable of cutting them at high speed. This object is solved by the material of independent claims I, II and III. Further advantageous features of these materials are described in the dependent claims. The invention also provides for use of these materials and for cutting tools made from these materials.
- The present invention provides cutting tools or materials therefor, which have high mechanical strength, are excellent in their durability, particularly heat-resistant property and wear-resistant property, and are capable of preventing them from fused adhesion with the work-piece.

Other details and advantages will become apparent in the entire disclosure.

- According to the present invention, in one aspect thereof, there is provided a material for cutting tools, which comprises in combination:

- a) a substrate based on a matrix composed of at least one selected from the group consisting of oxides, nitrides, carbides and oxinitrides of aluminum silicon and IVa group transition metal elements in the International Periodic Table, the substrate comprising 5 to 50% by weight of SiC whiskers with respect to said substrate, the whiskers being uniformly dispersed therein; and
- b) one or more coating layers composed at least one of oxides, nitrides, carbides, borides and oxinitrides, of at least one of aluminum, IVa and Va group transition metal elements in said Periodic Table, said coating layer being formed on the surface of said substrate to a thickness ranging from about 0.3 to about 20  $\mu\text{m}$ .

- According to the present invention, in a second aspect thereof, there is provided a material for cutting tools, which comprises in combination:

- a) a substrate based on an  $\text{Al}_2\text{O}_3$  matrix, and comprising 5 to 70% by weight of SiC whiskers, and  
 b) one or more coating layers composed of oxides, nitrides, carbides, carbonitrides, oxicarbides or oxycarbo-nitrides of IVa or Va group transition metal elements in the International Periodic Table, or oxide, nitride or oxinitride of aluminum, said coating layer being formed on the surface of said substrate to a thickness ranging from about 0.3 to about 20  $\mu\text{m}$ .

- According to the present invention, in a third aspect thereof, there is provided a material for cutting tools, which comprises in combination:

- a) a substrate based on an  $\text{Al}_2\text{O}_3$  matrix; and comprising 5 to 50% by weight of SiC whiskers; and 1 to 35% by weight of at least one of substituting component selected from the group consisting of metals of IVa, Va or VIa group transition metal elements in the International Periodic Table, oxides, nitrides, carbides or borides of these metallic elements, or solid-solutions of these compounds, and SiC; and  
 b) one or more coating layers composed of oxides, nitrides, carbides, carbonitrides, oxicarbides or oxycarbo-nitrides of IVa or Va group elements in the International Periodic Table, or oxide, nitride or oxinitride of aluminum, said coating layer being formed on the surface of said substrate to a thickness of about 0.3 to about 20  $\mu\text{m}$ .

- According to the present invention, in a fourth aspect thereof, there is provided a material for cutting tools, which comprises in combination:

- a) a substrate based on AlN matrix, and comprising 5 to 50% by weight of SiC whiskers; and

b) one or more coating layers composed of at least one of oxides, nitrides, carbides, carbonitrides, oxycarbides or oxicarbo-nitrides of IVa or Va group transition metal elements of the International Periodic Table, or oxide, nitride and oxinitride of aluminum, said coating layer being formed on the surface of said substrate to a thickness of from about 0.3 to about 20  $\mu\text{m}$ .

5. According to the present invention, in still other (fifth) aspect thereof, there are provided cutting tools which are made up of the abovementioned materials in foregoing various aspects of the present invention.

According to the present invention, in a still further aspect thereof, there is provided a method for high speed cutting of ferrous work-piece by use of the cutting tools.

When the ferrous work-piece is cut at a high speed, considerable rise in the cutting temperature is observed, on account of which the wear-resistant property and the mechanical strength of the cutting tool begin to decrease to bring about damage to the cutting tool. It is therefore considered favorable to employ a ceramic material having excellent heat-resistant property, as the principal component of the material for the cutting tools. However, the ceramic itself has, in general, low toughness, solution of this point being of consequence among other things. From this point of view, the present inventors have found out that it is preferable to use, as the principal component, those oxides, nitrides, oxinitrides and carbides of aluminum, or IVa or IVb group metals in the International Periodic Table, of which  $\text{Al}_2\text{O}_3$  AION, AlN,  $3\text{Al}_2\text{O}_3\text{SiO}_2$  (called "mullite") or TiC are particularly superior. The ceramics of these materials per se, however, are not satisfactory in their mechanical strength.

With a view to solving this problem, the present inventors conducted various studies and researches to increase the mechanical strength of the ceramic material without causing reduction in its heat-resistant property and the wear-resistant property. As the result, they have come to note that, when silicon carbide (SiC) whiskers having a high mechanical strength, high heat-resistant property and high heat conductivity are uniformly dispersed in the ceramic material, improvement in the material toughness can be attained effectively without losing its heat-resistant property. (Note: the technique of incorporating the whiskers in the ceramic material is disclosed in Japanese patent Kokai Publications No. 59-102862 and No. 59-102861 for the purpose of imparting high electrical conductivity to the material, and in USP 4,543,345 for the purpose of imparting toughness thereto; in these publications, however, no mention is made at all as to effectiveness of such techniques in obtaining the cutting tools of improved mechanical property, heat-resistance and wear-resistance.) It has, however, been found out that SiC per se (even SiC whiskers) possesses excellent affinity for iron, as its basic property, which causes the welded adhesion between the ferrous work-piece and the material constituting the cutting tool (more specifically, SiC whisker) during the high speed cutting, whereby there takes place removal of the SiC whiskers from the ceramic body to reduce the wear-resistance of the cutting tool to a considerable degree to render it unsuitable for practical use.

The present inventors, therefore, carried out further and repeated studies and researches to break through this problem, as the result of which they have discovered that, with a view to inhibiting the reaction between the SiC whiskers and the ferrous work-piece, the material for the cutting tool containing therein SiC as the reinforcing component may be coated with oxides, nitrides, carbides of aluminum (Al) or the IVa group transition metal elements in the International Periodic Table, or solid-solutions of these compounds.

On the other hand, the technique of improving the wear-resistant property of the matrix by providing a coating layer on a cemented carbide has been well known, as already mentioned in the foregoing. However, a combustion of the cemented carbide and the ceramic coating has generally low adhesion (or bonding) strength between them, hence both are apt to peel off easily. Further important is a point, in which the cemented carbide is apt to be subjected to plastic deformation due to heat and pressure to be generated at the time of the high speed cutting, whereby the cutting edge is rendered dull and blunt.

Also, a technique of coating an  $\text{Al}_2\text{O}_3$  ceramic body with an  $\text{Al}_2\text{O}_3$  layer has already been disclosed in, for example, Japanese patent kokoku publication No. 53-13276. This technique, however, is to render the surface of the  $\text{Al}_2\text{O}_3$  ceramic body to have a very fine grain size of  $\text{Al}_2\text{O}_3$  so that the wear-resistance of  $\text{Al}_2\text{O}_3$  may be improved by the increased mechanical strength thereof due to its reduction into the very fine grain size. On account of this, the prior art is particularly limited to the very fine grain size of  $\text{Al}_2\text{O}_3$  on the surface of the  $\text{Al}_2\text{O}_3$  substrate, as the essential construction thereof. According to the present invention, on the other hand, since the mechanical strength of the substrate is attained by incorporation of the whiskers, there will be no necessity for coating the surface of the substrate, for such purpose, as has been done in the prior art.

Throughout this application, the elements used will be defined in accordance with the International Periodic Table. The term "solid solution" refers to substances such as TiCO, TiCN, TiCNO etc. However, AION is not solid solution, rather, "AION" represents a generic term which includes  $\text{Al}_{17}\text{O}_{39}\text{N}$ ,  $\text{Al}_{(8/3)+x/3}\text{O}_4\text{xN}_x$  ( $0 < x < 0.5$ ),  $\text{Al}_{155}\text{O}_{228}\text{N}_4$  and the like, the AION compounds being variant due to each ratio of Al, O and N.

For the matrix to be used for the purpose of the present invention, there may preferably be used: (1) an Al type material such as, for example,  $\text{Al}_2\text{O}_3$ , AlN, AlON, or  $3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$  (mullite); or (2) a Ti type such as, for example, TiC; or (3) composite materials of the abovementioned (1) and (2) such as, for example,  $\text{Al}_2\text{O}_3\cdot \text{TiC}$ . The matrix essentially occupies the balance to SiC whiskers in the substrate. With a substituent component or a sintering aid referred hereinafter, the matrix amounts to at least 50 weight % per said balance. Further, for such matrix, mixtures of two or more of the abovementioned compounds and substances may be useful, of which combinations of  $\text{Al}_2\text{O}_3\cdot \text{TiC}$ ,  $\text{Al}_2\text{O}_3\cdot \text{AlON}$ ,  $\text{Al}_2\text{O}_3\cdot \text{AlON}\cdot \text{AlN}$ , AlON-AlN,  $3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2\cdot \text{TiC}$  and the like are preferable.

The quantity of the SiC whiskers to be included in the matrix should range generally from 5 to 50% by weight, or preferably from 5 to 30% by weight, more preferably from 15 to 30% by weight. When the SiC whisker content is below 5% by weight, no satisfactory toughness can be obtained; on the other hand, when the whiskers exceed 50% by weight, the matrix will generally have poor sinterability with the consequent inability to obtain the densely sintered body. However, in the case of  $\text{Al}_2\text{O}_3$  matrix, SiC whiskers may amount to up to 70% by weight, while up to 50% by weight is preferred for the practical productivity (second aspect).

The SiC whiskers may be selected as follows:

- a) diameter is in a range of from 0.1 to 2.0  $\mu\text{m}$ , or optimumly from 0.5 to 1.0  $\mu\text{m}$ ;
- b) length is 200  $\mu\text{m}$  or less, or more preferably 100  $\mu\text{m}$  or less, or optimumly 30  $\mu\text{m}$  or less; and
- c) aspect ratio is in a range of from 50 to 300; and
- d) density is about 3.2 g/cm<sup>3</sup> (i.e., the relative density is 95% or more). It is preferred that the whiskers having a length of 1 to 20  $\mu\text{m}$  are uniformly dispersed into the sintered body. The aspect ratio is preferably 2 to 30, more preferably 2 to 10, the crystal structure may be either of the  $\alpha$ -type or  $\beta$ -type.

According to a further aspect of the present invention the matrix may be substituted, in an amount of its 50% by weight or below (or depending on the substituent, 35% by weight or below, or 10% by weight or below) with at least one kind of substance selected from the group consisting of metallic elements of Al, Si and IVa, Va and VIa groups in the International Periodic Table, oxides, nitrides, carbides, and borides of these metallic elements, whereby it becomes possible to increase various properties of the matrix such as sinterability, heat-resistance, hardness, toughness, and so forth over the base matrix. For instance  $\text{ZrO}_2$  will render a higher toughness. (Note, here, SiC does not refer to whiskers, but powdery SiC.) When the substituent exceeds 50% by weight or above, the fundamental properties of the matrix per se cannot be taken advantage of. From this, a more acceptable amount of the matrix fraction to be substituted with the abovementioned metallic elements and their various compounds will be 35% by weight or below. The addition of the IVa (Ti, Zr, Hf), Va (V, Nb, Ta), and VIa (Cr, Mo, W) group elements or compounds thereof to the matrix would contribute to inhibition of the grain growth of the matrix during sintering, and formation of a highly densified sintered body. Preferred substitutive examples are Sample Nos. 5, 8, 12 and 16 in Example A2, Sample No. 1 in Example I, Sample No. 1 in Example, Sample Nos. 3 and 4 in Example E and the like. Certain substituting components constitute a part of the matrix component group. Under such conditions, the substituents may sometimes amount to 50 weight % or more per the entire matrix. Here, it is noted that the substituting component may hold concurrently a function as a sintering aid referred hereinafter. For example, substitution with AlN or  $\text{ZrO}_2$  for the  $\text{Al}_2\text{O}_3$  matrix; or substitution with  $\text{Al}_2\text{O}_3$  or compounds of IVa, Va or VIa-elements for the TiC matrix have dual functions, i.e., as the substituting component and as the sintering aid.

The substrate having a composition composed of the abovementioned matrices, the SiC whiskers, and further the substituent components should preferably have a relative density (to the theoretical one) of 97% or above, or more preferably 98% or above. Also, the average crystal grain size of the matrix should preferably be 5  $\mu\text{m}$  or below, or more preferably 3  $\mu\text{m}$  or below.

As for the coating layer, an average thickness of a hard coating layer should range from about 0.3 to about 20  $\mu\text{m}$ . When it is thinner than 0.3  $\mu\text{m}$ , no substantial effect of such coating layer can be obtained. On the other hand, when it is thicker than 20  $\mu\text{m}$ , it will have nothing to do with improvement in the wear-resistance, which is not only uneconomical, but also becomes liable to produce undesirable chipping.

This holds for single and multiply layers. 0.5  $\mu\text{m}$  to 15  $\mu\text{m}$  thickness is preferred. For the single layer, it is preferably from 1 to 10  $\mu\text{m}$ . For the multiply layers, the first (innermost) layer is preferably 0.2-5  $\mu\text{m}$ , more preferably 0.2-3  $\mu\text{m}$ ; while for the outer layer 1-10  $\mu\text{m}$  is preferred (more preferred 1-5  $\mu\text{m}$ ).

Materials for the coating layer may be appropriately determined in relation to the material constituting the substrate matrix. That is to say, of the coating layers, the one which is directly adhered onto the substrate (i.e., in the case of a single layer, the single layer per se; and, in the case of a plurality of layers, the innermost one which is to be positioned closest to the substrate) may be of the same metal component as that constituting the substrate matrix, whereby the adhesive strength between the substrate matrix and

the coating layer can be maintained in good condition even at a high temperature. More concretely, when the matrix for the substrate is an aluminum compound such as, for example,  $\text{Al}_2\text{O}_3$ ,  $\text{AlN}$ ,  $\text{AlON}$  or  $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$  (mullite), the adhering layer may also be composed of the Al-base substance such as, for example,  $\text{Al}_2\text{O}_3$ ,  $\text{AlN}$  or  $\text{AlON}$ . On the other hand, when the matrix is a compound of transition metals of IVa or Va group, e.g.,  $\text{TiC}$ , the adhering layer should preferably be of a Ti-base substance, such as  $\text{TiC}$ ,  $\text{TiN}$ ,  $\text{TiCN}$ ,  $\text{TiCO}$ ,  $\text{TiON}$ ,  $\text{TiCON}$ ,  $\text{TiO}_2$  or  $\text{TiB}_2$ .

5 Of the coating layers, the one to be in direct contact with a work-piece (the outermost layer, which, in the case of a single layer, may be the single layer per se; and, in the case of a plurality of layers, a layer which is at the farthest position from the substrate) may be composed based on aluminum or IVa group 10 transition metals. When the work-piece is cast iron, the coating layer should preferably be  $\text{Al}_2\text{O}_3$ ,  $\text{AlON}$  or  $\text{TiC}$ , or more preferably  $\text{TiC}$ . On the other hand, when the work-piece is of alloy steel in general, the coating layer should preferably be of  $\text{Al}_2\text{O}_3$ ,  $\text{AlON}$  or  $\text{TiC}$ , or more preferably  $\text{Al}_2\text{O}_3$ .

15 As for the method of manufacturing such cutting tools, the substrate therefor is produced by sintering. For the sintering method, there may be adopted various methods such as, for example, normal sintering or pressure-sintering like hot pressing (HP) or hot isostatic pressing (HIP). Referring to the sintering condition, it is preferred that a compact is sintered at 1600-1950 °C for 0.25 to 1 hour. In the HP method, the pressure may be 100 - 400 kg/cm<sup>2</sup>. For sintering, there may be added an appropriate sintering aid. More specifically, in the case with the  $\text{Al}_2\text{O}_3$  type matrix, there may preferably be added  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{ZrO}_2$ ,  $\text{NiO}$ ,  $\text{SiO}_2$ ,  $\text{Y}_2\text{O}_3$ , oxides of rare earth elements, or mixtures of these compounds. In the case with the  $\text{AlN}$  type matrix, there 20 may preferably be added, for example,  $\text{CaO}$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Mo}$ ,  $\text{W}$ ,  $\text{Mo}_2\text{C}$ ,  $\text{WC}$ , oxides of the rare earth elements, or a mixture of these compounds. Such sintering aid should preferably be 10% by weight or below, or more preferably 5% by weight or below, in general from the standpoint of heat conductivity, mechanical strength at high temperature, and others.

25 The coating layer can be disposed on the surface of the substrate in various manners such as, for example, chemical vapor deposition (CVD) method, physical vapor deposition (PVD) method, or physico-chemical deposition method. The CVD technique is suitable for multi-coating, while the PVD technique is suitable for single-coating, particularly of a large thickness. According to the PVD technique, a compression stress remains in the coating layer, resulting in a superior fracture resistance.

30 The cutting tools according to the present invention are highly suited for the high speed cutting (generally, at 500 m/min. or above, or 800 m/min. or above) of ferrous work-pieces. However, the applicable cutting speed depends on the nature of the work and ranges about 300m/min or more for the hard material (e.g., Test Example 2), or about 700m/min or more for the relatively soft material. The range of the ferrous work-pieces which can be successfully cut is extensive, and the cutting tools exhibit excellent cutting property not only on cast iron, but also on steel. In other words, the cutting tool according to the present 35 invention is significantly small in the wear in respect of the flank and the cutting face of the work-piece, and yet offers no chipping, fracture, and so on. In particular, the cutting tool made of the aluminum-based matrix is suitable for cutting the work-piece of alloy steel in general, and, the cutting tool made of the TiC-based matrix is suitable for cutting the work-piece of ductile cast iron (a ferrous material which is recognized by those skilled in the art to be very difficult to cut among various cast irons).

40 With a view to enabling those persons skilled in the art to readily practise the present invention, the following several preferred examples are presented along with some cutting test examples.

#### EXAMPLES A1 AND A2

45 Starting material powder of  $\text{Al}_2\text{O}_3$  having an average particle size of 0.7  $\mu\text{m}$ , SiC whiskers having a diameter of from 0.1 to 1.0  $\mu\text{m}$  (the principal diameter thereof being from 0.2 to 0.5  $\mu\text{m}$ ), a length of from 50 to 200  $\mu\text{m}$ , an aspect ratio of from 50 to 300, and a density of 3.19 g/cm<sup>3</sup>, and an additive(s) having an average particle size of from 0.5 to 3.0  $\mu\text{m}$  were mixed in accordance with the ratios as shown in Table I or 50 2 below. This mixture of the starting material was mixed in a ball mill for a period of time from 2 to 48 hours, after which it was dried to obtain a base powder for the substrate.

55 Then, this base powder was sintered in a graphite mold by the hot pressing (HP) method at a temperature ranging from 1,600°C to 1,950°C, for a period of time from 15 minutes to one hour, and under a pressure of 200 kg/cm<sup>2</sup>. The thus obtained sintered body was subjected to cutting and grinding based on "SNGN 432" to thereby prepare a substrate. In the subsequent step, a coating layer also as shown in Table I or 2 below was placed on the surface of this substrate by a chemical vapor deposition (CVD) method, thereby manufacturing the cutting tool.

Table 1

Sample Nos.		Substrate		Coating Layer			Average Thick-ness (μm)	$K_{IC}$ (MN/m <sup>3/2</sup> )
		$Al_2O_3$ (wt%)	SiC Whiskers (wt%)	first	second	third		
Example (A)	1	80	20	$Al_2O_3$			1	5.7
	2	"	"	AlON	TiCNO		2	5.7
	3	"	"	AlN	$Al_2O_3$		3	5.7
	4	50	50	TiC			3	7.9
	5	40	60	TiN			8	8.4
	6	92	8	AlON	$Al_2O_3$		4	4.4
	7	70	30	$Al_2O_3$	TiC		10	6.4
	8	60	40	HfC			1	7.5
	9	75	25	TiN			4	6.1
	10	90	10	TiC	TiN		6	4.6
	11	"	"	$Al_2O_3$			0.5	4.6
	12	70	30	TiCO	AlON	$Al_2O_3$	7	6.4
	13	"	"	TiN			5	6.4
	14	"	"	AlON	ZrC		5	6.4
Comparison (A)	1	60	40	-			-	7.5
	2	"	"	TiC			0.1	7.5
	3	90	10	TiN	$Al_2O_3$		22	4.6
	4	97	3	$Al_2O_3$			2	3.8
	5	30	70	AlON	$Al_2O_3$		5	-*
	6	$Al_2O_3$ single system**	"	-				3.2
	7			$Al_2O_3$			2	3.2

\* It was impossible to determine  $K_{IC}$  value because of insufficient sintering.

\*\* High pure  $Al_2O_3$  was HIP sintered to obtain the substrate.

Table 2

Sample Nos.		Substrate			Coating Layer			Average Thick-ness (μm)
		Al <sub>2</sub> O <sub>3</sub> (wt%)	SiC Whiskers (wt%)	Substituent (wt%)	first	second	third	
Example (A2)	1	75	10	TiC 15	AlON	Al <sub>2</sub> O <sub>3</sub>	TiC	4
	2	82	7	TiN 10	ZrC 1	Al <sub>2</sub> O <sub>3</sub>		1
	3	70	10	TiB <sub>2</sub> 20		Al <sub>2</sub> O <sub>3</sub>		2
	4	80	15	ZrO <sub>2</sub> 5		Al <sub>2</sub> O <sub>3</sub>		2
	5	70	20	ZrO <sub>2</sub> 10		AlON	Al <sub>2</sub> O <sub>3</sub>	4
	6	72	25	HfO <sub>2</sub> 3		TiC		5
	7	63	7	TiC 15	TiN 15	TiN		5
	8	64	18	TiC 15	Ta 3	AlON	Al <sub>2</sub> O <sub>3</sub>	4
	9	53	45	WC 2		TiC	TiN	10
	10	70	20	WC 5	TaC 5	AlN	AlON	6
	11	77	10	ZrO <sub>2</sub> 8	TiN 5	Al <sub>2</sub> O <sub>3</sub>		3
	12	75	10	TiC 10	W <sub>8</sub> 5	AlON	Al <sub>2</sub> O <sub>3</sub>	6
	13	65	15	TiC 15	Mo <sub>8</sub> 5	Al <sub>2</sub> O <sub>3</sub>		3
	14	65	20	ZrO <sub>2</sub> 10	ZrN 5	TiC	HfN	13
	15	79	15	TiN 5	ZrC 1	TiCO	TiN	8
	16	70	15	SiC 15		TiCNO	Al <sub>2</sub> O <sub>3</sub>	8
	17	74	20	TiC 5	Ti 1	AlON	ZrC	5
Comparison (A2)	1	75	10	TiB <sub>2</sub> 15		-		-
	2	50	40	TiC 10		Al <sub>2</sub> O <sub>3</sub>		0.1
	3	65	35	-		TiC		5
	4	25	60	TiC 15		Al <sub>2</sub> O <sub>3</sub>		3
	5	50	10	TiB <sub>2</sub> 40		Al <sub>2</sub> O <sub>3</sub>		2
	6	Al <sub>2</sub> O <sub>3</sub> single system				-		

EXAMPLE 8

In the same manner as in Examples A1 and A2 above, the cutting tools were manufactured, with the exception that AlN powder (having an average particle size of 1.0  $\mu\text{m}$ ) was used as the matrix material for  
5 the substrate.

The conditions for manufacturing the same are shown in Table 3 below.

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Table 3

Sample Nos.	Substrate			Coating Layer			K <sub>IC</sub> (MN/m <sup>3/2</sup> )	
	Al <sub>2</sub> O <sub>3</sub> (wt%)	SiC Whiskers (wt%)	Sintering Aid (wt%)	First	Second	third		
	Y <sub>2</sub> O <sub>3</sub>	1	AlON	Al <sub>2</sub> O <sub>3</sub>	TiN	Average Thick- ness (μm)	Relative Density (%)	
Example (E)	1	93	6	SiO <sub>2</sub>	0.5	W	15	99
	2	77.5	20	Y <sub>2</sub> O <sub>3</sub>	1	AlON	6	99
	3	88	10	SiO <sub>2</sub>	1	TiC	8	99
	4	67	30	Y <sub>2</sub> O <sub>3</sub>	2	Al <sub>2</sub> O <sub>3</sub>	5	98
	5	77.5	20	CaO	0.5	Mo	7	99
	6	76.5	20	SiO <sub>2</sub>	0.5	WC	3	98
	7	82	15	Y <sub>2</sub> O <sub>3</sub>	1	Mo <sub>2</sub> C	2	98
	8	48	45	SiO <sub>2</sub>	4	Y <sub>2</sub> O <sub>3</sub>	3	98
	9	83	15	Y <sub>2</sub> O <sub>3</sub>	2	AlON	5	99
	10	83	"	SiO <sub>2</sub>	2	TiC	3	98
Comparison (B)	11	53	"	Al <sub>2</sub> O <sub>3</sub>	30*	Y <sub>2</sub> O <sub>3</sub>	2	7.0
	1	99	-	Y <sub>2</sub> O <sub>3</sub>	1	AlN	Al <sub>2</sub> O <sub>3</sub>	5.5
	2	38	55	SiO <sub>2</sub>	4	Mo	3	5.8
	3	58	30	SiO <sub>2</sub>	5	Y <sub>2</sub> O <sub>3</sub>	7	5.7

\* Substituent  
\*\* It was impossible to determine K<sub>IC</sub> value because of insufficient sintering.

EXAMPLES C, D AND E

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In the same manner as in Examples A1 and A2 above, cutting tools were manufactured, with the exception that AlON powder (having an average particle diameter of 0.8  $\mu\text{m}$ ), 3Al<sub>2</sub>O<sub>3</sub>-2SiO<sub>2</sub> powder (having an average particle diameter of 0.7  $\mu\text{m}$ ), or TiC powder (having an average particle diameter of 0.8  $\mu\text{m}$ ) was used as matrix material for the substrate.

10 The conditions for the manufacture thereof are shown in the following Table 4.

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Table 4

Sample Nos.	Matrix (wt%)	Substrate				Coating Layer			Average Thick- ness (μm)
		SiC Whiskers (wt%)	Third Component* (wt%)			First	Second	third	
			a	b					
Example (C)	1 AlON	59	7	AlN 30	CaO 2 Y <sub>2</sub> O <sub>3</sub> 2	AlN	AlON	Al <sub>2</sub> O <sub>3</sub>	13
	2	64	12	Al <sub>2</sub> O <sub>3</sub> 20	"	AlON	Al <sub>2</sub> O <sub>3</sub>		2
	3	76	15	TiN 15	"	AlN	Al <sub>2</sub> O <sub>3</sub>		2
	4	66	20	Al <sub>2</sub> O <sub>3</sub> 10	"	Al <sub>2</sub> O <sub>3</sub>			0.8
	5	56	40	-	"	TaC	TiN		5
	6	50	20	Al <sub>2</sub> O <sub>3</sub> 10	AlN 19	AlON	Al <sub>2</sub> O <sub>3</sub>		3
Example (D)	1 3Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub>	81	6	ZrO <sub>2</sub> 10	Y <sub>2</sub> O <sub>3</sub> 3	Al <sub>2</sub> O <sub>3</sub>			1
	2	79	10	TiC 10	Y <sub>2</sub> O <sub>3</sub> 1	TiC	HfO <sub>2</sub>		3
	3	79	20	-	"	AlN	AlON	Al <sub>2</sub> O <sub>3</sub>	3
	4	69	30	-	"	TiN			5
	5	54	45	-	"	Al <sub>2</sub> O <sub>3</sub>			2
Example (E)	1 TiC	68	5	Al <sub>2</sub> O <sub>3</sub> 25	MgO 2	TiC	Al <sub>2</sub> O <sub>3</sub>		3
	2	85	10	Al <sub>2</sub> O <sub>3</sub> 3	Dy <sub>2</sub> O <sub>3</sub> 2	TiC			2
	3	49	15	{Ti <sub>4</sub> Al <sub>2</sub> O <sub>3</sub> 30}	Dy <sub>2</sub> O <sub>3</sub> 1	TiC			2
	4	70	20	Cr <sub>3</sub> C <sub>2</sub> 10		HfO <sub>2</sub>			4
	5	50	30	{TiN 10 Cr <sub>3</sub> C <sub>2</sub> 10}		TiN	TiC		5
	6	40	40	Cr <sub>3</sub> C <sub>2</sub> 20		TiB <sub>2</sub>			1
	7	68	20	Al <sub>2</sub> O <sub>3</sub> 10	Dy <sub>2</sub> O <sub>3</sub> 2	TiN	TiC		6
	8	78	15	ZrO <sub>2</sub> 5	Y <sub>2</sub> O <sub>3</sub> 2	ZrC			2
Comparison (C)	1 AlON	96	-	-	CaO 2 Y <sub>2</sub> O <sub>3</sub> 2	AlON	Al <sub>2</sub> O <sub>3</sub>		2
Comparison (D)	1 3Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub>	89	10	-	Y <sub>2</sub> O <sub>3</sub> 1	Al <sub>2</sub> O <sub>3</sub>			0.1
Comparison (E)	1 TiC	48	30	Al <sub>2</sub> O <sub>3</sub> 20	MgO 2	TiC	Al <sub>2</sub> O <sub>3</sub>		30
	2	42	20	{Al <sub>2</sub> O <sub>3</sub> 10 ZrO <sub>2</sub> 25}	MgO 3	TiC			8

\* Third component (a) is substituent component, and third component (b) is sintering aid.

TEST EXAMPLE 1

With use of the cutting tools obtained in Example A above, the cutting tests were conducted to examine the wear of the tools on the flank and the face of a work-piece.

5 The conditions for the test are as follows.

Work: "SCR 420" carburized material

Cutting speed: 500 m/min.

Rate of feed: 0.31 mm/rev.

Depth of cut: 1 mm

10 Wear: quantity after passage of 1 min. 15 sec.

The test results are as shown in the following Table 5.

TEST EXAMPLE 2

15 With use of the cutting tools obtained in Example A2 above, the cutting tests were conducted to examine the wear of the cutting tools on the flank and the face of the work-piece.

The conditions for the test are as follows.

Work: "SNCM 8" (HB 300)

20 Cutting speed: 350 m/min.

Rate of feed: 0.3 mm/rev.

Depth of cut: 1 mm

Wear: quantity after passage of 1 min. 15 sec.

The test results are as shown in the following Table 6.

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Table 5

Sample Nos.	Wear	
	flank (mm)	face (mm)
Example (A1)	1	0.06
	2	0.06
	3	0.04
	4	0.08
	5	0.10
	6	0.04
	7	0.05
	8	0.13
	9	0.11
	10	0.09
	11	0.10
	12	0.05
	13	0.12
	14	0.07
	15	0.12
	16	0.05
	17	0.06
Comparison (A1)	1	0.40
	2	0.35
	3	Fracture
	4	1.2*
	5	Fracture
	6	Chipping
	7	Chipping

\* It occurred unusual wear owing to chipping.

Table 6

Sample Nos.	Wear	
	flank (mm)	face (mm)
Example (A2)	1	0.09
	2	0.09
	3	0.08
	4	0.08
	5	0.07
	6	0.13
	7	0.10
	8	0.08
	9	0.12
	10	0.07
	11	0.08
	12	0.07
	13	0.09
	14	0.10
	15	0.09
	16	0.09
	17	0.08
Comparison (A2)	1	0.33
	2	0.52
	3	Chipping
	4	Fracture
	5	Fracture
	6	Fracture

TEST EXAMPLE 3

- 5      With use of the cutting tools obtained in Examples A to E above, and those obtained in Comparative Examples, the cutting tests were carried out to examine the wear of the cutting tools on the flank and the face of the work-piece.
- 10     The conditions for the test are as follows.
- 10     Work: "SNCM 8" (HB 300)
- 10     Cutting speed: 450 m/min.
- 10     Depth of cut: 1 mm
- 10     Rate of feed: 0.15 mm/rev.
- 10     Cutting time: 1 min.
- 15     The test results are as shown in the following Table 7 and 8.

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Table 7

Sample Nos.	Wear	
	flank (mm)	face (mm)
Example (B)	1*	0.06
	2	0.06
	3	0.11
	4	0.10
	5	0.09
	6	0.15
	7	0.09
	8	0.14
	9	0.08
	10	0.13
	11	0.12
Comparison (B)	1	Fracture
	2**	Chipping
	3	Fracture
	4	0.36
		0.40

\* Partial chipping.

\*\* It occurred unusual wear owing to chipping.

Table 8

Sample Nos.	Wear	
	flank (mm)	face (mm)
Example (A1)	3	0.05
	7	0.07
	9	0.16
	11	0.10
Example (A2)	5	0.06
	12	0.06
Example (C)	1	0.06
	2	0.09
	3	0.09
	4	0.15
	5	0.14
	6	0.15
Example (D)	1	0.10
	2	0.15
	3	0.09
	4	0.20
	5	0.08
Example (E)	2	0.20
	7	0.24
Comparison (C)	1	fracture after 23 seconds
Comparison (D)	1	0.66
		0.45

TEST EXAMPLE 4

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With use of the cutting tools obtained in Examples A1, A2, B and E above as well as those obtained in Comparative Examples, the cutting tests were carried out to examine the wear of the cutting tools with respect to the flank and the face of the work-piece.

The conditions for the test are as follows.

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Work: "FCD 45" (HB 180)

Cutting speed: 500 m/min.

Depth of cut: 0.5 mm

Rate of feed: 0.2 mm/rev.

Cutting time: 20 min.

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The test results are as shown in the following Table 9.

As is apparent from the Table 9, the cutting tools obtained in Example E (i.e., made of the TiC substrate) is particularly suitable for the high speed cutting of the ductile cast iron.

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TEST EXAMPLE 5

With use of the cutting tools obtained in Examples A1, A2 and B above, the cutting tests were carried out to examine the wear of the cutting tool with respect to the flank and the face of the work-piece.

The conditions for the test are as follows.

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Work: "SCM 415"

Cutting speed: 800 m/min.

Depth of cut: 3 mm

Rate of feed: 0.31 mm/rev.

Cutting time: 5 min.

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The test results are as shown in the following Table 10.

This test is of an example of cutting a work-piece at a considerably high speed.

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Table 9

Sample Nos.		Wear	
		flank (mm)	face (mm)
Example (A1)	7	0.45	0.16
Example (A2)	5	0.47	0.16
Example (B)	2	0.48	0.17
	1	0.33	0.07
	2	0.31	0.07
	3	0.38	0.10
Example (E)	4	0.40	0.13
	5	0.42	0.12
	6	0.39	0.10
	7	0.35	0.08
	8	0.40	0.09
Comparison (E)	1	microchipping after 15 seconds	
	2	0.67	0.40

Table 10

Sample Nos.		Wear	
		flank (mm)	face (mm)
Example (A1)	6	0.20	0
	9	0.38	0
Example (A2)	3	0.23	0
	14	0.35	0.10
Example (B)	2	0.22	0
	8	0.42	0.11
Comparison (A)	1	1.20	0.81
Comparison (A2)	1	Chipping	
Comparison (B)	14	0.98	0.51

So far the present invention has been described with reference to preferred examples of the cutting tools and the results of the cutting tests thereon. It should however be noted that the invention is not limited to these examples alone, but any changes and modifications may be made by those persons skilled in the art in the component materials thereof without departing from the spirit and scope of the invention as recited in the appended claims.

45      **Claims**

- I. A material for cutting tools, which comprises in combination:
  - a) a substrate based on a matrix composed of at least one selected from the group consisting of oxides, nitrides, carbides and oxinitrides of aluminum silicon and IVa group transition metal elements in the International Periodic Table, the substrate comprising 5 to 50% by weight of SiC whiskers with respect to said substrate, the whiskers being uniformly dispersed therein; and
  - b) one or more coating layers composed at least one of oxides, nitrides, carbides, borides and oxinitrides of at least one of aluminum, IVa and Va group elements in said Periodic Table, said coating layer being formed on the surface of said substrate to a thickness ranging from about 0.3 to about 20  $\mu\text{m}$ .
2. Material for cutting tools as set forth in Claim 1, wherein said matrix for the substrate is at least one selected from the group consisting of  $\text{Al}_2\text{O}_3$ , AlN, AION,  $3\text{Al}_2\text{O}_3\text{-}2\text{SiO}_2$  (mullite) and TiC.
3. Material for the cutting tools as set forth in Claim 1, wherein the quantity of said SiC whiskers is in a range of from 5 to 30% by weight, preferably 15 to 30 % by weight.

4. Material for cutting tools as set forth in one of the preceding claims, wherein a layer to be in direct contact with said substrate, among said coating layers, is composed of the same metallic component as that of said matrix for the substrate.
5. Material for cutting tools as set forth in Claim 4, wherein the metallic component of said matrix for the substrate is aluminum, and at least the layer to be in direct contact with said substrate is composed of aluminum.
6. Material for cutting tools as set forth in Claim 5, wherein said matrix for the substrate is composed of one selected from the group consisting of  $\text{Al}_2\text{O}_3$ , AlN, AlON and  $3\text{Al}_2\text{O}_3\text{-}2\text{SiO}_2$ , and said layer to be in direct contact with said substrate is composed of one selected from the group consisting of  $\text{Al}_2\text{O}_3$ , AlN and AlON.
- 10 7. Material for cutting tools as set forth in Claim 4, wherein the metallic component of said matrix for the substrate is composed of one of the elements belonging to the IVa group of the Periodic Table, and at least the layer to be in direct contact with said substrate is composed of one of elements belonging to the IVa group of the Periodic Table.
- 15 8. Material for cutting tools as set forth in Claim 7, wherein said matrix for the substrate is TiC, and said layer to be in direct contact with said substrate is one selected from the group consisting of TiC, TiN, TiCN, TiCO, TiON and TiCON.
9. Material for cutting tools as set forth in one of the preceding claims, wherein the metallic component of a layer to be in contact with a work-piece, among said coating layers, is one selected from the group consisting of aluminum and the group IVa elements of the Periodic Table.
- 20 10. Material for cutting tools as set forth in one of the preceding claims, wherein no more than 50% by weight of the substrate matrix has been substituted with at least one substituent component selected from the groups consisting of metals, oxides, nitrides, carbides, and borides of elements Al, Si, and IVa, Va and VIa groups of the International Periodic Table.
- II. A material for cutting tools, which comprises in combination:
- 25 a) a substrate based on an  $\text{Al}_2\text{O}_3$  matrix, and comprising 5 to 70% by weight of SiC whiskers, and  
 b) one or more coating layers composed of oxides, nitrides, carbides, carbonitrides, oxycarbides or oxycarbo-nitrides of IVa or Va group elements in the International Periodic Table, or oxide, nitride or oxinitride of aluminum, said coating layer being formed on the surface of said substrate to a thickness ranging from about 0.3 to about 20  $\mu\text{m}$ .
- 30 12. A material for cutting tools as set forth in claim II in which the substrate based on an  $\text{Al}_2\text{O}_3$  matrix comprises 5 to 50% by weight of SiC whiskers; and 1 to 35% by weight of at least one of substituting component selected from the group consisting of metals of IVa, Va or VIa group elements in the International Periodic Table, oxides, nitrides, carbides or borides of these metallic elements, or solid-solutions of these compounds, and SiC.
- 35 13. A material for cutting tools, which comprises in combination:  
 a) a substrate based on AlN matrix, and comprising 5 to 50% by weight of SiC whiskers; and  
 b) one or more coating layers composed of at least one of oxides, nitrides, carbides, carbonitrides, oxycarbides or oxycarbo-nitrides of IVa or Va group elements of the International Periodic Table, or oxide, nitride and oxinitride of aluminum, said coating layer being formed on the surface of said substrate to a thickness of from about 0.3 to about 20  $\mu\text{m}$ .
- 40 14. Material for cutting tools as set forth in any one of the preceding claims, wherein said coating layer is a single layer of 1-10  $\mu\text{m}$  in thickness.
15. Material for cutting tools as set forth in any one of Claims I to I3, wherein said coating layer has a multiply layer structure with an innermost layer being 0.2-5  $\mu\text{m}$  and an outer layer being 1-10  $\mu\text{m}$  in thickness.
- 45 16. Use of a material according to one of the preceding claims for cutting a ferrous work piece.
17. Cutting tool composed of the material as set forth in any one of claims I to I5.
18. A method for cutting a ferrous work-piece by means of the cutting tool as set forth in Claim I6.
19. A method for cutting as set forth in Claim I8, wherein the cutting operation is done at a high speed.